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YAWSONDE TESTING OF CONCEPTS FOR THE 155MM INTERMEDIATE VOLATILITY AGENT PROJECTILE

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Three projectile concepts for the 155mm intermediate volatility agent (IVA) system were tested at Dugway Proving Ground, UT, on 2 December 1981. Two launch conditions were fired: Charge M4A2 Zone 4/533 mils and PXR6297/1100 mils. All rounds were yawsonde-instrumented. Yawsonde data did not show any abnormal behavior and all rounds were stable.

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I. INTRODUCTION

Three 155mm intermediate volatility agent (IVA) canister configurations were flight tested on 2 December 1981 at Dugway Proving Ground (DPG), Utah. Two launch conditions were selected: Charge M4A2 Zone 4/quadrant elevation 533 mils and proof charge PXR6297/quadrant elevation 1100 mils. An M109A1 with a yaw inducer was used for the Zone 4 rounds, while an M198 with a standard muzzle brake was used for the PXR6297 rounds. All of the rounds tested were stable, and no single configuration displayed flight characteristics that were superior to the other configurations. During this test, small sample sizes were used and were intended to identify the presence of gross flight instabilities. Further aeroballistic testing will be required when a final selection of the agent system is made. Only low viscosity liquid simulants (Ethanol/Freon 113) were utilized for the present test. The use of higher viscosity simulants could dramatically change the flight performance of any of the configurations that were tested.

II. BACKGROUND

Preliminary field testing of 155mm IVA configurations was conducted at DPG between 1972-1976.[1,2,3,4,5,6,7] These tests did not address the flight

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1. *George Travers and C. C. Sterns, "Feasibility Test of Projectile, 155mm, Binary, IVA Test Plan," Deseret Test Center, DTC-TP-73-307, Fort Douglas, Utah, December 1972.*

2. *C. C. Sterns and CPT J. Martin, "Advanced Development Test (Cloud Characteristics) for Projectile, 155mm, Binary, IVA Data Report," Dugway Proving Ground, DPG-DR-74-305, Dugway, Utah, February 1974.*

3. *George Travers and C. C. Sterns, "Research Test (Cloud Characteristics) of Projectile, 155mm, Binary, IVA Test Plan," Dugway Proving Ground, DPG-TP-74-315, Dugway, Utah, April 1974.*

4. *C. C. Sterns and CPT J. Martin, "Research Test of Projectile, 155mm, Binary, IVA Data Report," Dugway Proving Ground, DPG-DR-74-314, Dugway, Utah, May 1974.*

5. *C. C. Sterns and CPT J. Martin, "Research Test (Cloud Characteristics) of Projectile, 155mm, Binary, IVA Data Report," Dugway Proving Ground, DPG-DR-74-315, Dugway, Utah, July 1974.*

6. *Wilbert T. Taylor and William C. McIntyre, "Research Test of Projectile, 155mm, Binary, IVA (Chemical Dissemination of Simulant) Test Plan," Dugway Proving Ground, DPG-TP-D112A, Dugway, Utah, May 1975.*

7. *J. R. Deal and CPT S. A. Oaks, "Research Test of Projectile, 155mm, Binary, IVA Data Report," Dugway Proving Ground, DPG-DR-76-312, Dugway, Utah, June 1976.*

stability of the projectile system. Reference 2 documented unstable flights, but details of the canister configurations were omitted. A partial description of the hardware is extracted from pages 1-5 of Reference 2. "The projectiles were assembled with dual canisters and expelling charges. Eight of the short canisters (the forward canisters) were thin wall in design with plastic liners. Eight of the short canisters were thick wall design without plastic liners. The 16 long canisters (the rear canisters) were of thick wall design. The projectiles were equipped with mechanical time fuzes (mostly M577 fuzes)." Dramatic flight instabilites occurred for most of the "thick wall short canister" projectiles when fired with charge M4A2 Zone 7 at 500 mils quadrant elevation (QE). A second firing was made using M3A1 Zone 4 at 1100 mils for the two same designs. Results indicated that the "thick walled" shell were stable, while "radar data indicated a slight instability" for two of the "thin walled" shells. The short canisters were filled with N-Propyl-Bromide* while the long canisters were filled with N-Butyl-Acetate* Details such as the internal dimensions of the canisters were not provided in the test report and could not be traced.

During these early test programs,[1-7] a dudding problem with the M577 fuze was postulated. In response to this concern, a yawsonde/vibration package was built and tested, but no anamolous flight behavior was observed.[8] The canister design was probably the "thin wall" type, but new simulants were used. (See Reference 8 for details.)

Hardware designs for the IVA concept have usually involved canisters with unequal internal diameters as opposed to the 155mm M687 GB system where the canisters have equal internal diameters (Fig. 1). Since stability analyses for liquid-filled shell are normally restricted to cylinders of a single diameter, gyroscope models were tested to investigate the effects of unequal internal diameters.[9] The canister geometry for the M687 was selected by using the inviscid Stewartson theory[10] and applying the viscous corrections of Wedemeyer.[11] These analyses indicate that the liquid moment can become large (and destabilize the projectile) if the fast precessional frequency of the yawing motion is dangerously close to certain of the natural frequencies (eigenfrequencies) of oscillation of the liquid. If the liquid is spinning as a rigid body, the natural frequencies depend principally upon the aspect ratio

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* *Properties of the chemical species are noted for historical reasons only.*

8. *W. P. D'Amico, "An Investigation of the Flight Vibration Environment of the 155mm M687-IVA Projectile," BRL Memorandum Report No. 2755, June 1977 (AD B019792L).*

9. *W. P. D'Amico, Jr., and M. D. Fuller, "Experimental Study of a Liquid-Filled Cylinder with Unequal Internal Diameters," ARBRL-MR-03070, January 1981 (AD A096800).*

10. *K. Stewartson, "The Stability of a Spinning Top Containing Liquid," Journal of Fluid Mechanics, Vol. 5, 1959, pp. 557-592.*

11. *E. H. Wedemeyer, "Viscous Corrections to Stewartson's Stability Criterion," BRL Report No. 1325, June 1966 (AD 489687).*

of the cylinder (height/diameter), the fill ratio, and the Reynolds number. For the case of a cylinder with unequal diameters, an average aspect ratio can be derived using the total height and the volume. This average aspect ratio was used with the Stewartson-Wedemeyer theory to design and evaluate the gyroscope experiments.[9] The data suggested that the average aspect ratio concept could not adequately predict the motion of the gyroscope and should only be used for rough engineering approximations.

Interest in the IVA unequal internal diameter concept continued, and a series of yawsonde-instrumented tests were conducted by the BRL at the Transonic Range Facility, Aberdeen Proving Ground, MD.[12] A description of the projectile hardware and a round-by-round summary are provided in Tables 1 and 2, respectively. No flight instabilities were observed.

TABLE 1. PHYSICAL CHARACTERISTICS OF 155MM
155MM IVA SHELL FOR APG TESTS[a]

		Moments of Inertia		Canister Dimensions				
	Mass	I_x	I_y	Top Canister		Rear Canister		
Type	(kg)	($kg \cdot m^2$)	($kg \cdot m^2$)	L (cm)	D (cm)	L (cm)	D (cm)	c/a
M687	41.95	0.1617	1.767	19.30	10.74	28.57	10.74	4.457
Model A	45.12	0.1733	1.691	15.85	10.80	34.46	11.11	4.469
Model B	46.17	0.1728	1.841	16.84	10.80	32.95	11.43	4.438

a Measurements taken with filled canisters.

12. *W. P. D'Amico, Jr., and W. H. Clay, "Yawsonde Tests for Prototypes of the 155mm Intermediate Volatility Agent Projectile," ARBRL-MR-03185, July 1982 (AD A117575).*

TABLE 2. ROUND-BY-ROUND SUMMARY FOR APG TESTS

Projectile[a] Number	BRL Number	Firing Date	Muzzle Velocity (m/s)	FMA[b] (degrees)	Quadrant Elevation (degrees)	Launch Condition[c]
195B	1626	27 Aug 80	336.2	9.5	30	Chg 4/YI
187A	1627	27 Aug 80	349.0	9.5	30	Chg 4/YI
194B	1720	27 Aug 80	338.3	9.5	30	Chg 4/YI
186A	1721	27 Aug 80	337.4	8.5	30	Chg 4/YI
193A	1718	28 Aug 80	334.4	12.5	30	Chg 4/YI
185A	1713	28 Aug 80	339.5	12	30	Chg 4/YI
192B	1714	28 Aug 80	336.8	11.5	30	Chg 4/YI
184A	1715	28 Aug 80	340.5	8	30	Chg 4/YI
189B	1624	28 Aug 80	458.4	---	67	Chg 6
181A	1625	28 Aug 80	462.1	---	67	Chg 6
191A	1716	28 Aug 80	460.9	3	17	Chg 6
183A	1697	28 Aug 80	463.3	---	17	Chg 6

[a] A-type shell contained canisters with a 0.793 cm (5/16 inch) wall thickness, while B-type shell had 0.635 cm (1/4 inch) wall canisters.

[b] FMA is defined as the first maximum angle of yaw and is determined as half of the first peak-to-peak excursion in Sigma N. FMA is taken only as a measure of the first maximum yaw level.

[c] Yaw induction (YI) with a modified muzzle brake with full (12.7 cm) side plates.

III. TEST PROGRAM

A. Hardware.

A cutaway view of an M687 projectile showing the metal payload canisters and the plastic liners is shown in Figure 1. Figures 2-4 are sketches of the three canister concepts that were tested at DPG, while Table 3 gives pertinent physical characteristics and a comparison with the standard M687 hardware. A simple design concept was applied to select the hardware dimensions: Adopt the M687 aspect ratio as a standard. Hence, all configurations had c/a approximately equal to 4.5. In cases where the front and rear canisters had unequal internal diameters, the average aspect ratio concept from Reference 9 was used. Concept A is essentially an M687. (Canisters with equal internal diameters were utilized, as well as the large spacer in the rear of the aft canister.) An all-steel rear canister was utilized (wall thickness of 0.953 cm

TABLE 3. COMPARISON OF DPG PROTOTYPE 155MM IVA PROJECTILES WITH THE 155MM M687 GB PROJECTILE[1]

	M687		Concept A[2]		Concept C		Concept D	
	Rear	Front	Rear	Front	Rear	Front	Rear	Front
Internal Canister Lengths (cm) (w/o cutters and spacers)	28.02	18.79	33.36	14.48	31.24	17.25	33.30	16.25
Overall Internal Length (cm)	48.31		48.44		49.25		50.31	
Internal Canister Diameter (cm)	10.69	10.69	10.80	10.69	11.43	10.03	11.43	10.67
Thickness of Discontinuity Between Forward and Rear Canisters (cm)	0		0.05		0.70		0.38	
Wall Thickness of Steel Canisters (cm)	0.30	0.30	0.95	0.30	0.63	0.63	0.63	0.63
Wall Thickness of Plastic Canisters (cm)	0.63	0.63	N/A	0.63	N/A	0.63	N/A	0.32
Mass of Liquid Payload (kg)	1.81	2.06	2.15	1.60	2.26	1.68	2.40	1.77
Mass of Filled Canisters (kg)	6.39	4.62	13.63	4.40	10.69	7.45	10.97	7.18
Mass of Projectile Metal Parts (kg) (w/o canister and liquid)	31.07		29.06		28.95		28.95	
Total Projectile Assembly Mass (kg)	42.08		47.09		47.09		47.10	
Projectile Asembly Center of Gravity (m from the base)	0.34		0.31		0.32		0.32	
Total Projectile Assembly Axial Moment of Inertia ($kg \cdot m^2$)[3]	0.16		0.18		0.18		0.18	
Total Projectile Assembly Transverse Moment of Inertia ($kg \cdot m^2$)[3]	1.82		1.82		1.91		1.90	
Aspect Ratio (Internal Height/ Internal Diameter)[4]	4.52		4.50		4.50		4.50	

[1] Data obtained from J. M. Hayner, Chemical Systems Laboratory.

[2] Not the same configuration as Model A used in the APG yawsonde tests.

[3] Liquid payload considered to be frozen.

[4] For cases where unequal canister internal diameters exist, an average radius is computed from the volume and the overall length. This average radius is used to compute the aspect ratio.

or 3/8 inch). Concepts C and D are throwbacks to the "thick wall-thin wall" forward cylinders of Reference 2. The rear canisters of these two designs are all steel, have the same wall thickness (0.635 cm or 1/4 inch), but have different lengths. The forward canisters of the C and D concepts have plastic liners. One liner is twice the thickness of the other, thus producing a larger step between the forward and rear canisters. Since Reference 2 did not provide a complete description of all canister dimensions, it is not clear how the C and D configurations are related to the hardware of Reference 2. The Models A and B of Reference 12 (Tables 1 and 2) are not similar to the C and D concepts.

B. Test Site.

The German Village test range at DPG was utilized for this test. The M109A1 and M198 weapons were located side by side on the test pad to minimize the time required to relocate velocimeters and to reposition telemetry receiving antennas. DPG operated a modified Hawk radar. Only the Chg 4/W flights were successfully tracked over the entire flight path by the Hawk. The PXR 6297 flights have ranges beyond the maximum range capability of the Hawk. Radar data were not processed for this report. DPG personnel also set up and operated a ground receiving station for the yawsonde data. This station was located approximately 200m to the rear and 60m to the south of the weapons. A time-zero pulse from the gun was recorded, as well as a range IRIG-B time signal.

C. Characteristics of Yawsonde Data for the Test Conditions.

The data obtained by a yawsonde device are in the form of the complementary solar aspect angle (Sigma N) and the spin. Sigma N is the complement of the solar aspect angle, which is the angle between a vector drawn to the sun and the spin axis of the projectile. Local excursions in Sigma N are a measure of the yaw about the trajectory. Spin data are in the form of the time derivative of the Eulerian roll angle ($\dot{\phi}$) of the shell. $\dot{\phi}$ is a good approximation to the spin when the angular motion is small. However, oscillations are present in $\dot{\phi}$ histories, and the mean of these oscillations is considered to be the spin. Hence, the $\dot{\phi}$ data are simply labeled as spin. At various times during the downrange flight, the yaw data transmission may be poor due to nulls in the radiation pattern of the yawsonde antenna. The noise results in a temporary loss in data. All of the yawsonde units were configured in the shape of a standard fuze.[13]

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13. *William H. Mermagen and Wallace H. Clay, "The Design of a Second Generation Yawsonde," BRL Memorandum Report No. 2368, April 1974 (AD 780064).*

Two launch conditions were tested and the details of the yawsonde data will be different at each condition. Projectile in-flight motion is usually characterized by an oscillatory behavior with two distinct frequencies: fast precession (8-20Hz) and slow precession (1Hz). For a Chg 4 launch, a standard muzzle break was modified to induce yaw at launch. The motion generated by such a launch typically consists of half fast and half slow precession. A measure of the launch disturbance can be obtained by the maximum excursion in σ_N first observed after launch. Half of this first maximum amplitude (FMA) is often taken to be equivalent to the first maximum yaw that the projectile experiences. For a stable flight this initial yaw disturbance will decay, and a small amplitude, slow precessional motion should result. For rounds launched with the proof charge PXR6297 a standard muzzle brake is required. Due to the supersonic launch condition and the standard muzzle brake, the yaw history will be radically different from the low velocity launches. The first portion of the trajectory will have very small angular motion, but small slow precessional motion will occur when transonic/subsonic velocities exist. This will take place on the upleg at approximately 15-30 seconds. Apogee will occur at approximately 45-50 seconds. Subsequent to the summital maneuver, slow precessional motion will increase as the nose of the projectile seeks to follow the trajectory. The projectile will then gain speed and become supersonic prior to impact. This will result in a reduction of the amplitude of the slow precessional motion. A small amplitude fast precessional motion may occur along the trajectory, and such motion should probably be attributed to the liquid payload. The main purpose of these preliminary yawsonde tests is to determine if fast precessional motion is present and if that motion damps or is amplified by the liquid payload.

A round-by-round summary of the program is given in Table 4. Several of the yawsondes did not perform properly. Data were lost on several flights as indicated in Table 4. Also, many of the data transmissions were quite noisy, resulting in a poor resolution of the yawing motion.

D. <u>PXR6297/QE=1100 Mils Data</u>.

Figures 5a and 5b give the yaw and spin data for Round A4. Figures 6a and 6b provide similar data for Round A5. Expanded plots of the yaw for Round A5 are given in Figures 6c and 6d. The fast precessional mode is approximately 24Hz with an amplitude of less than 0.5 degrees. Data for Round C6 were quite noisy, but are provided in Figures 7a and 7b. The yaw data during the 80-100 second-time frame may not be correct due to the noise, and an expanded plot (Fig. 7c) does not resolve the issue. Data for Round D4 are given in Figures 8a and 8b.

E. <u>CHG4W/QE=533 Mils Yaw Induced</u>.

Figures 9a and 9b give data for Round A1. Large initial yaws (FMA = 8 degrees) were induced (exceeding the launch window since $\sigma_N > 60^0$), but no instability occurred. Data for Round A2 are shown in Figures 10a and 10b (FMA = 6 degrees). The initial data for Round C1 were quite noisy and good data were not obtained until approximately 8 seconds into the flight (Figs. 11a and

11b). Rounds D1 and D2 were stable (Figs. 12a, 12b, 13a, 13b), but data were not obtained during the early portions of the trajectory.

TABLE 4. ROUND-BY-ROUND SUMMARY - 155MM IVA YAWSONDE TEST
2 December 1981
Dugway Proving Ground, Utah

CSL#	BRL#	Comments	Muzzle Velocity (m/s)	Launch Time (MST)
LAUNCH CONDITION - PXR6297/1100 MILS				
A4	1773	no data	854.6	1021
A5	1803	spin & yaw	857.2	1044
A6	1789	spin & yaw	858.8	1102
C4	1792	no data	854.6	1115
C5	1793	no data	855.8	1124
C6	1794	spin & yaw	853.1	1132
D4	1795	spin & yaw	-----	1142
D5	----	not tested	-----	----
D6	----	not tested	-----	----
LAUNCH CONDITION - Chg 4/W/533 MILS YAW INDUCED				
A1	1590	spin & yaw	322.1	1338
A2	1650	spin & yaw	329.3	1345
A3	1756	no data	330.8	1351
C1	1758	spin & yaw	329.4	1356
C2	1762	poor transmission	329.2	1401
C3	1767	poor transmission	329.7	1406
D1	1768	spin & yaw	331.3	1411
D2	1769	spin & yaw	329.7	1427
D3	1804	no data	330.9	1433

IV. CONCLUSIONS

No unstable flights were observed for any of the canister configurations that were tested. The yawsonde data were not excellent in quality, but no irregular flight behavior was observed. Further testing will be required if the IVA liquid components have substantially different kinematic and mass properties than the simulants used during this test.

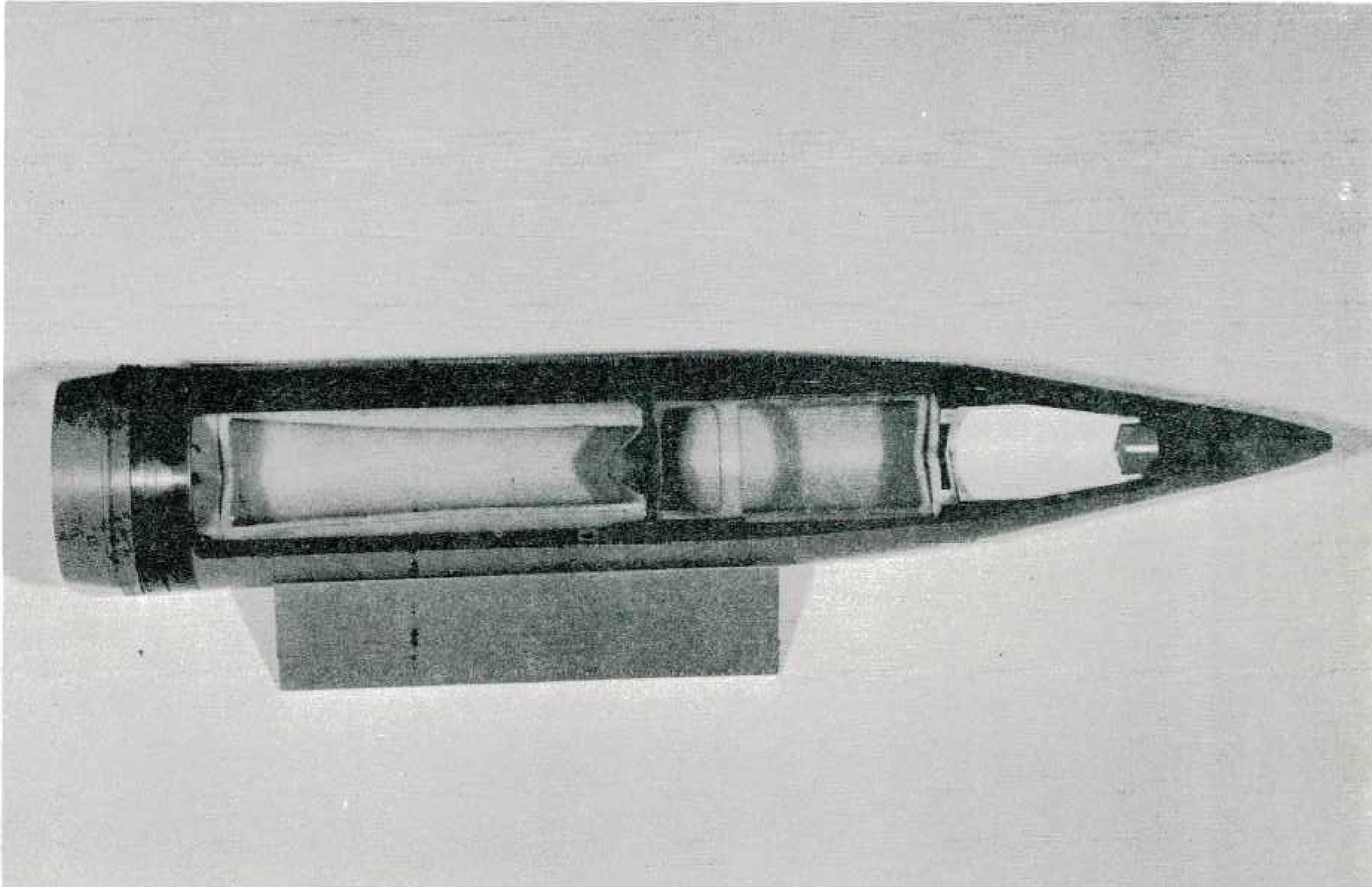
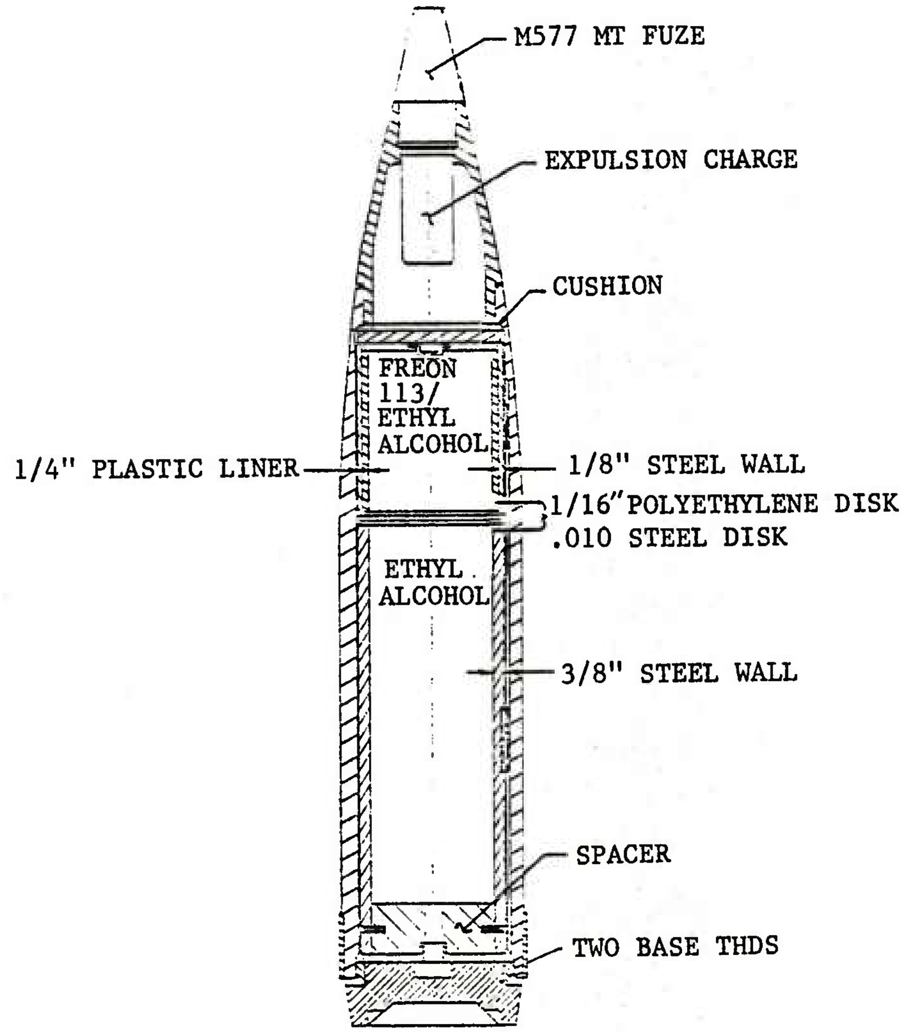


Figure 1. Cutaway View of a Prototype M687 Projectile.



CONCEPT "A"

Figure 2. Cutaway View of 155mm Concept A.

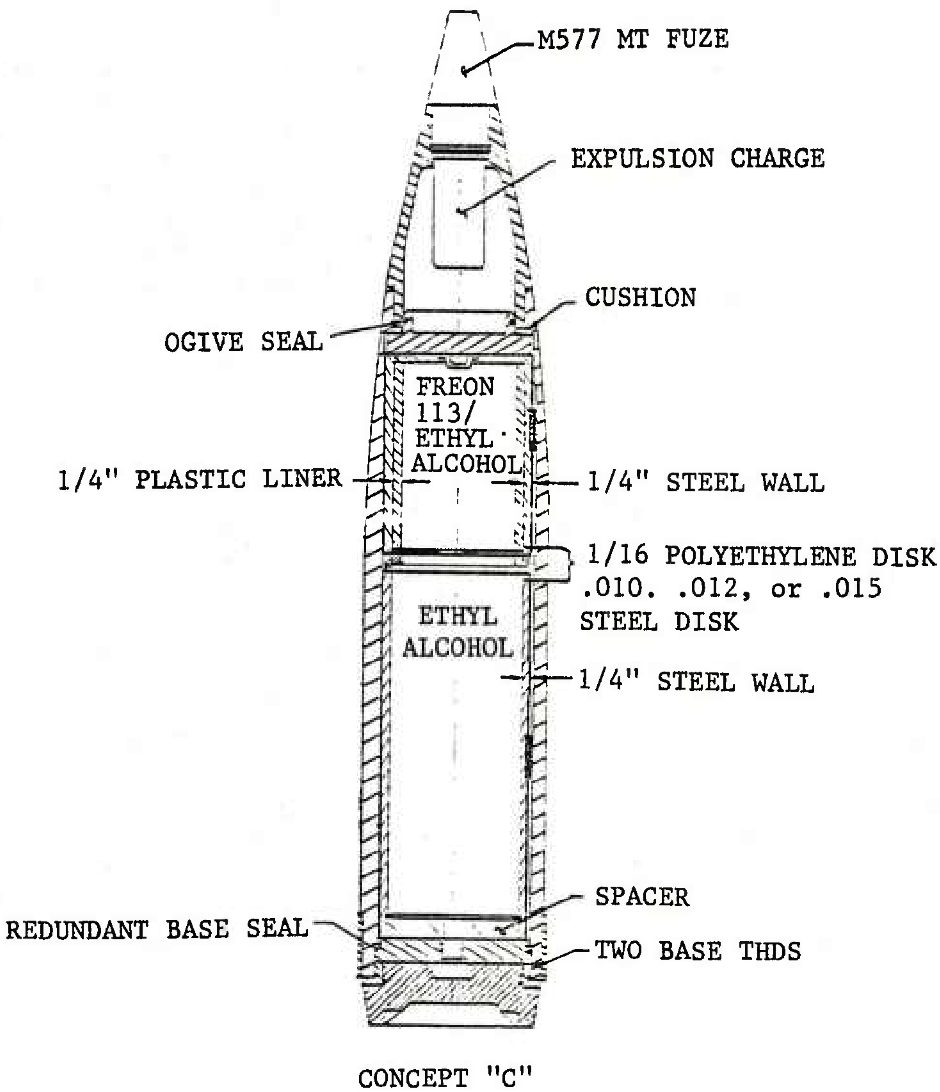


Figure 3. Cutaway View of 155mm Concept C.

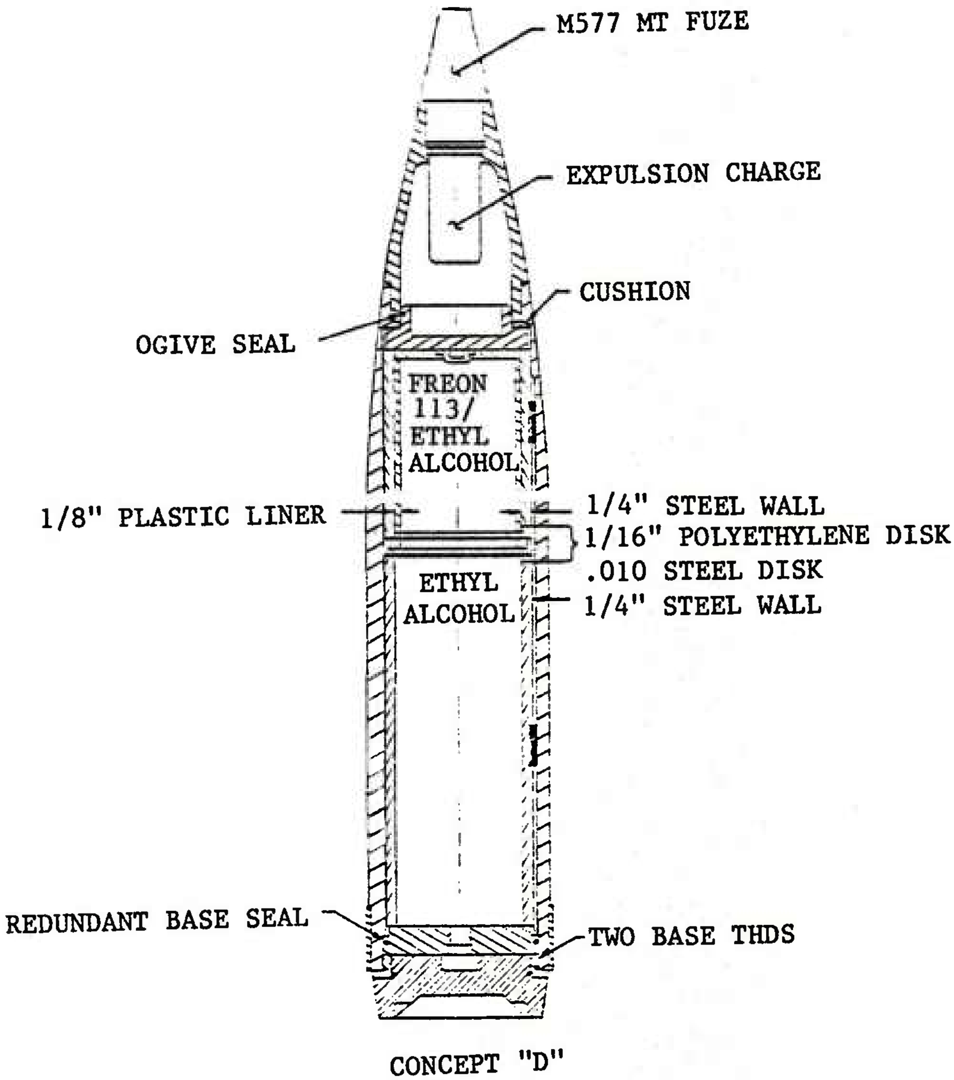


Figure 4. Cutaway View of 155mm Concept D.

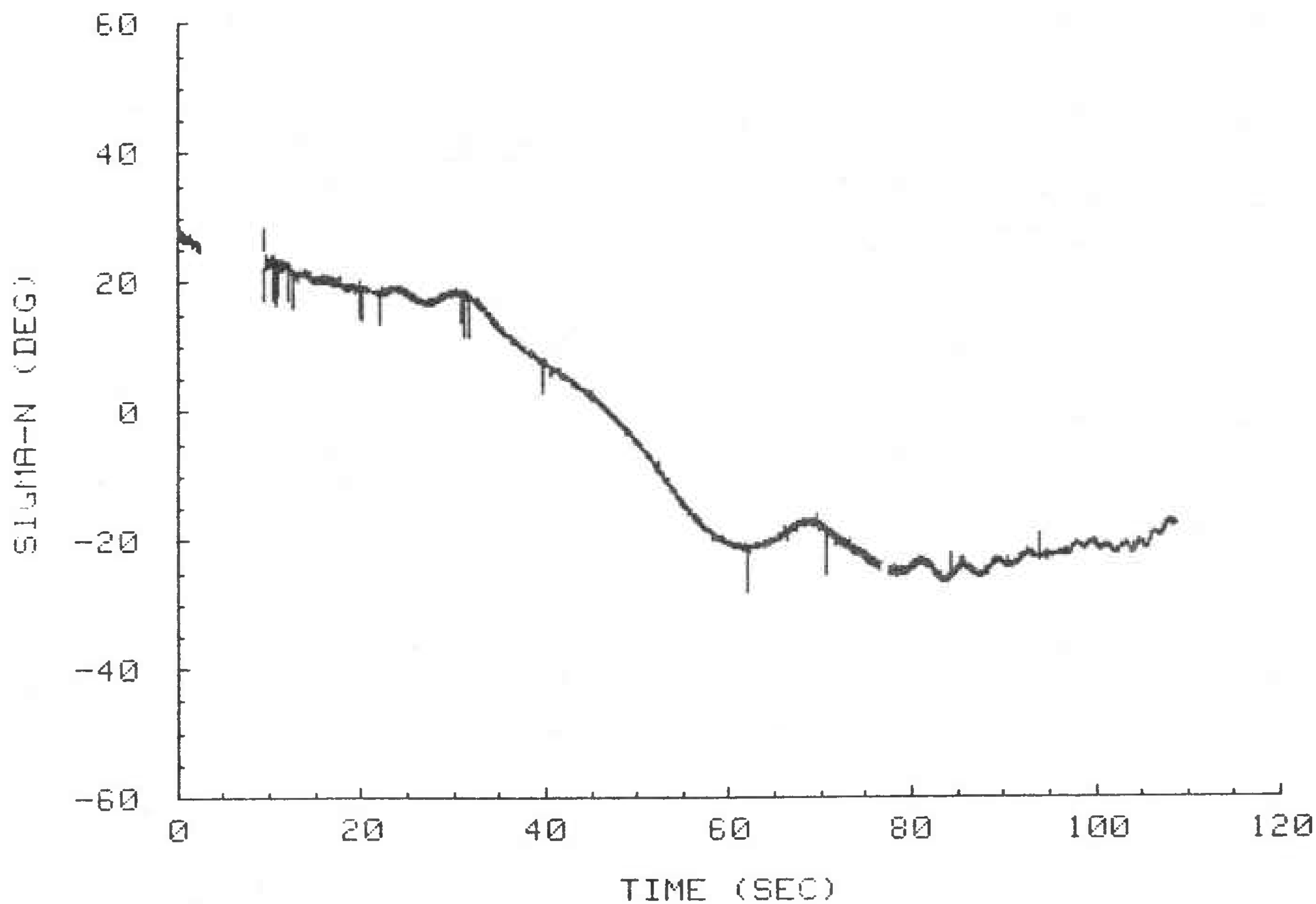


Figure 5a. Sigma N versus Time for Round A5.

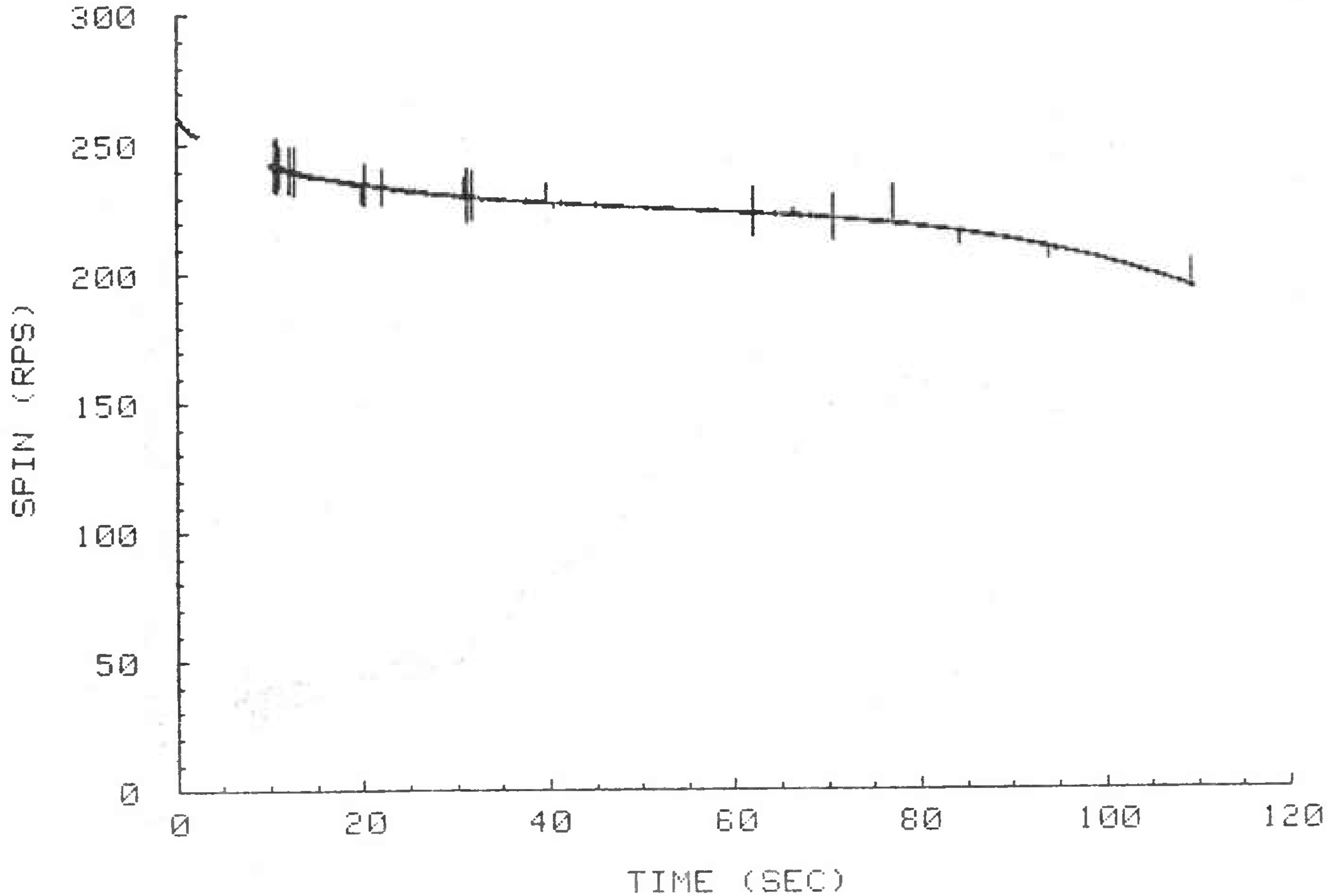


Figure 5b. Spin versus Time for Round A5.

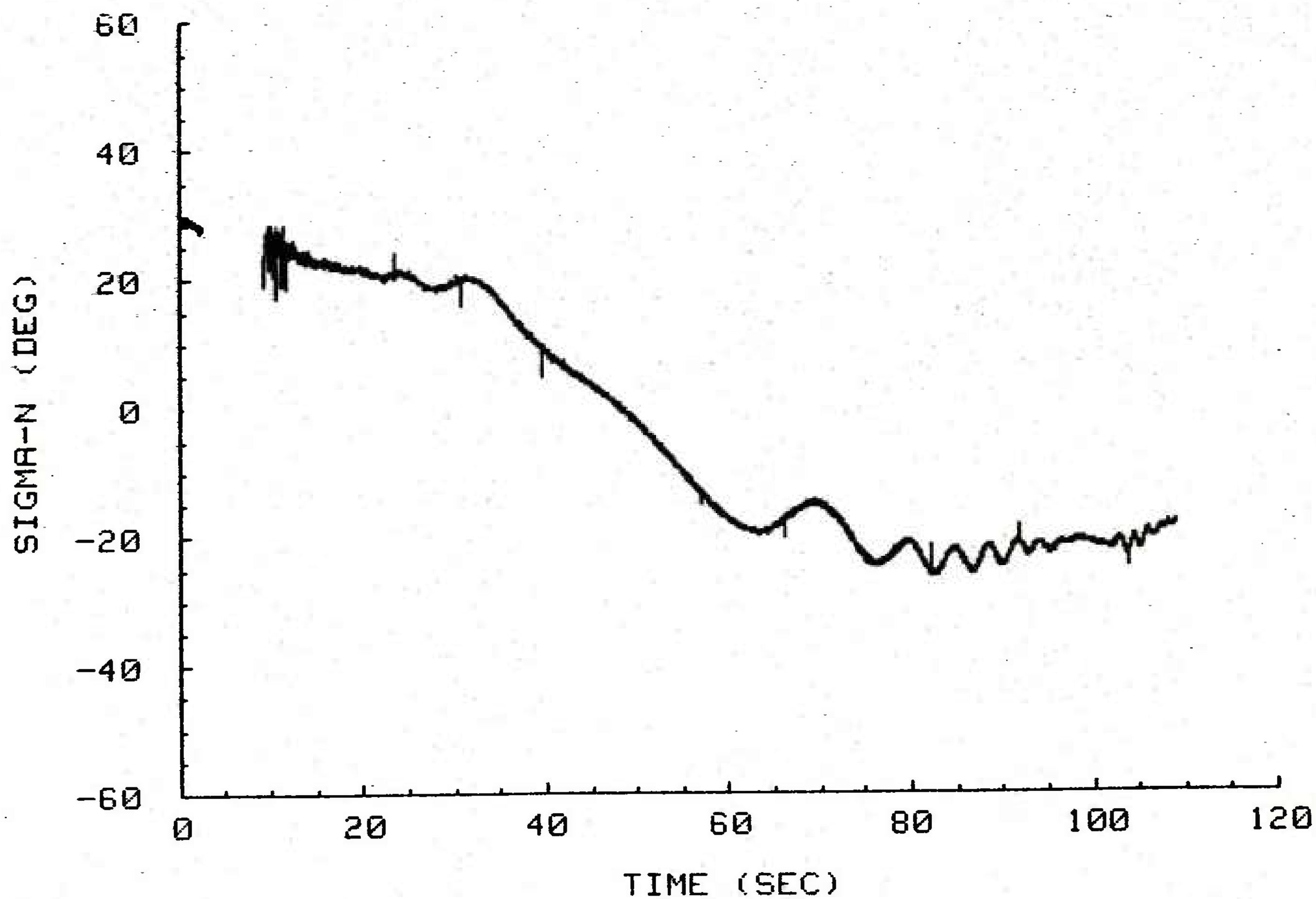


Figure 6a. Sigma N versus Time for Round A6.

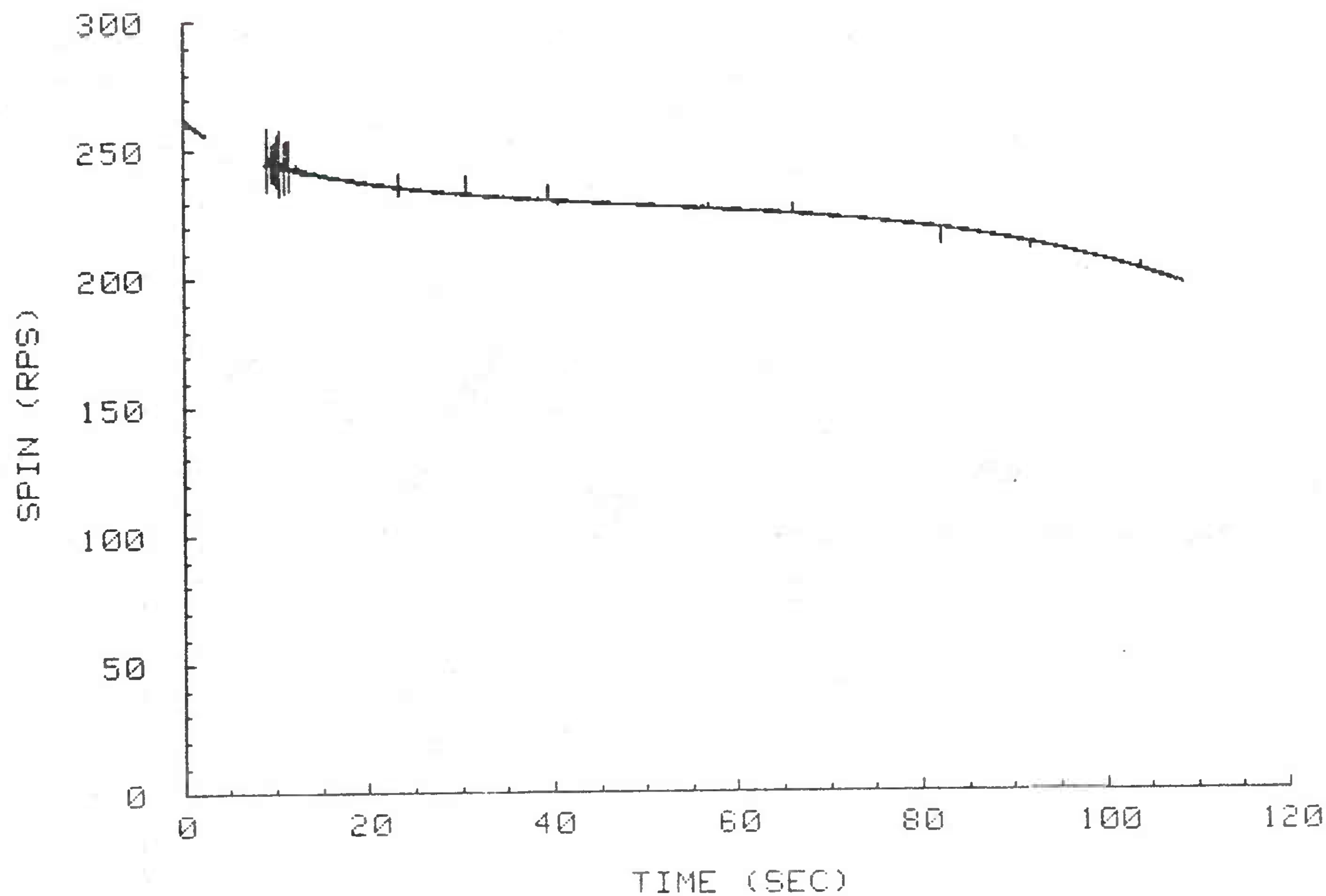


Figure 6b. Spin versus Time for Round A6.

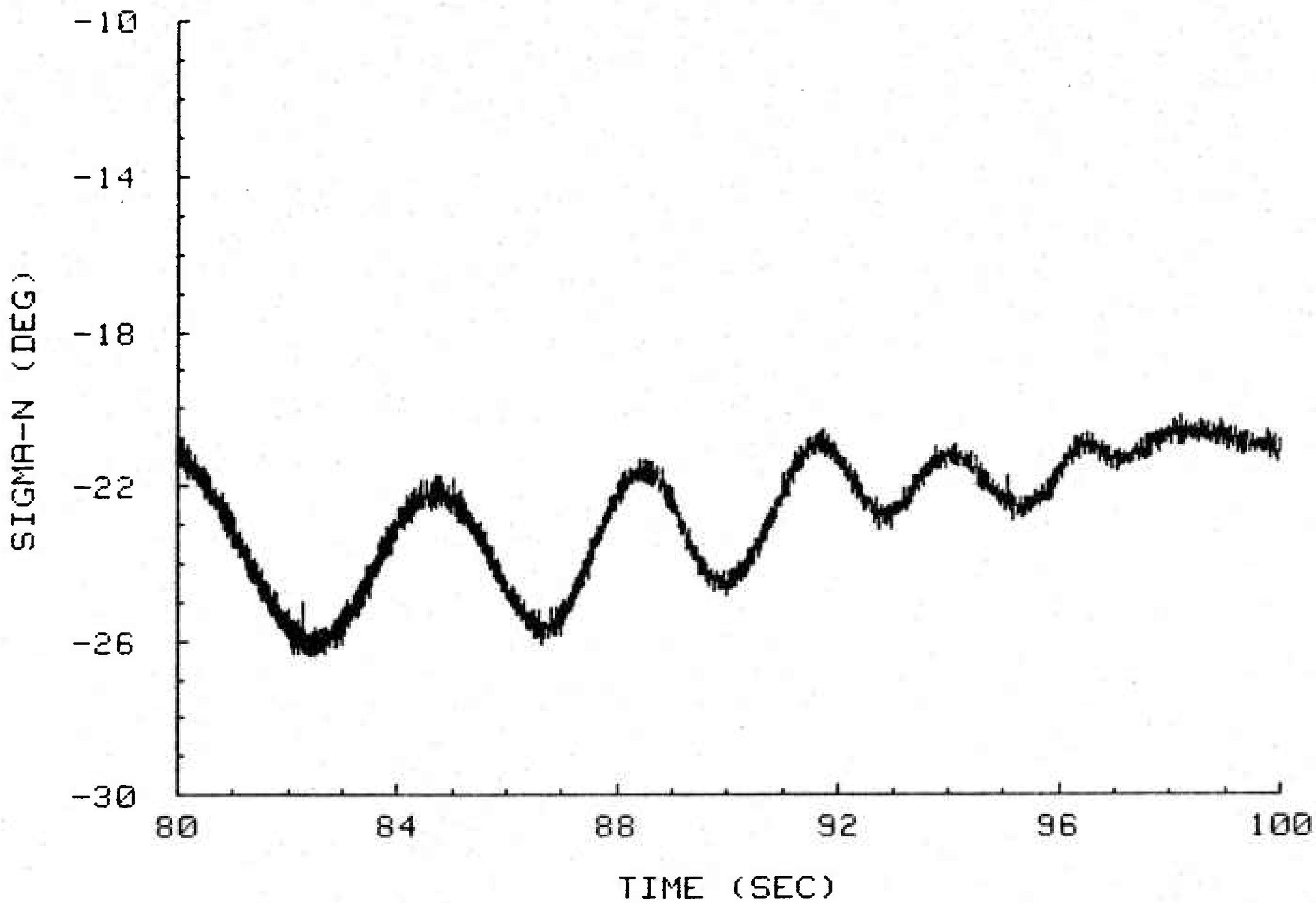


Figure 6c. Expanded Sigma N History (80-100 Sec) for Round A6.

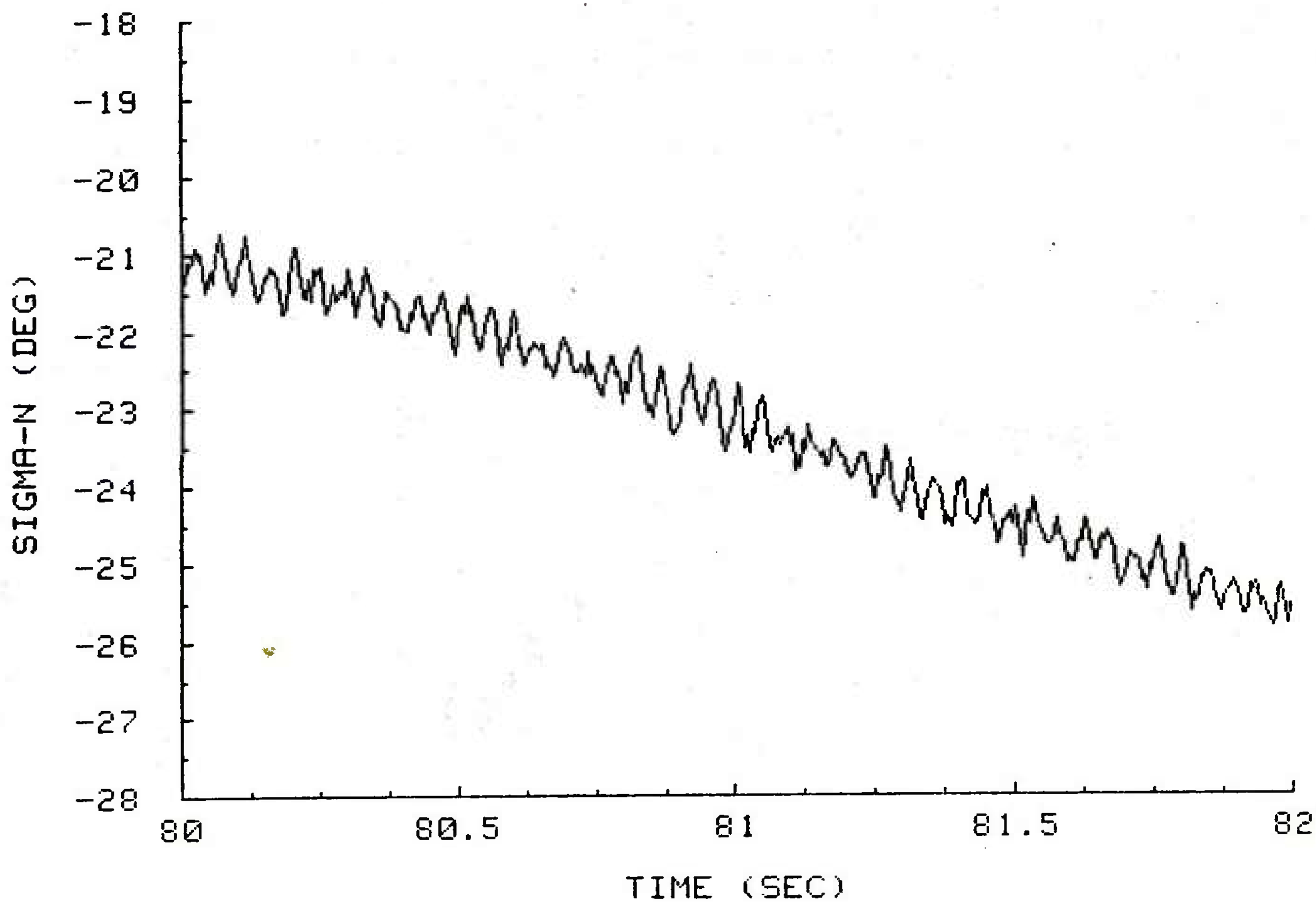


Figure 6d. Expanded Sigma N History (80-82 Sec) for Round A6.

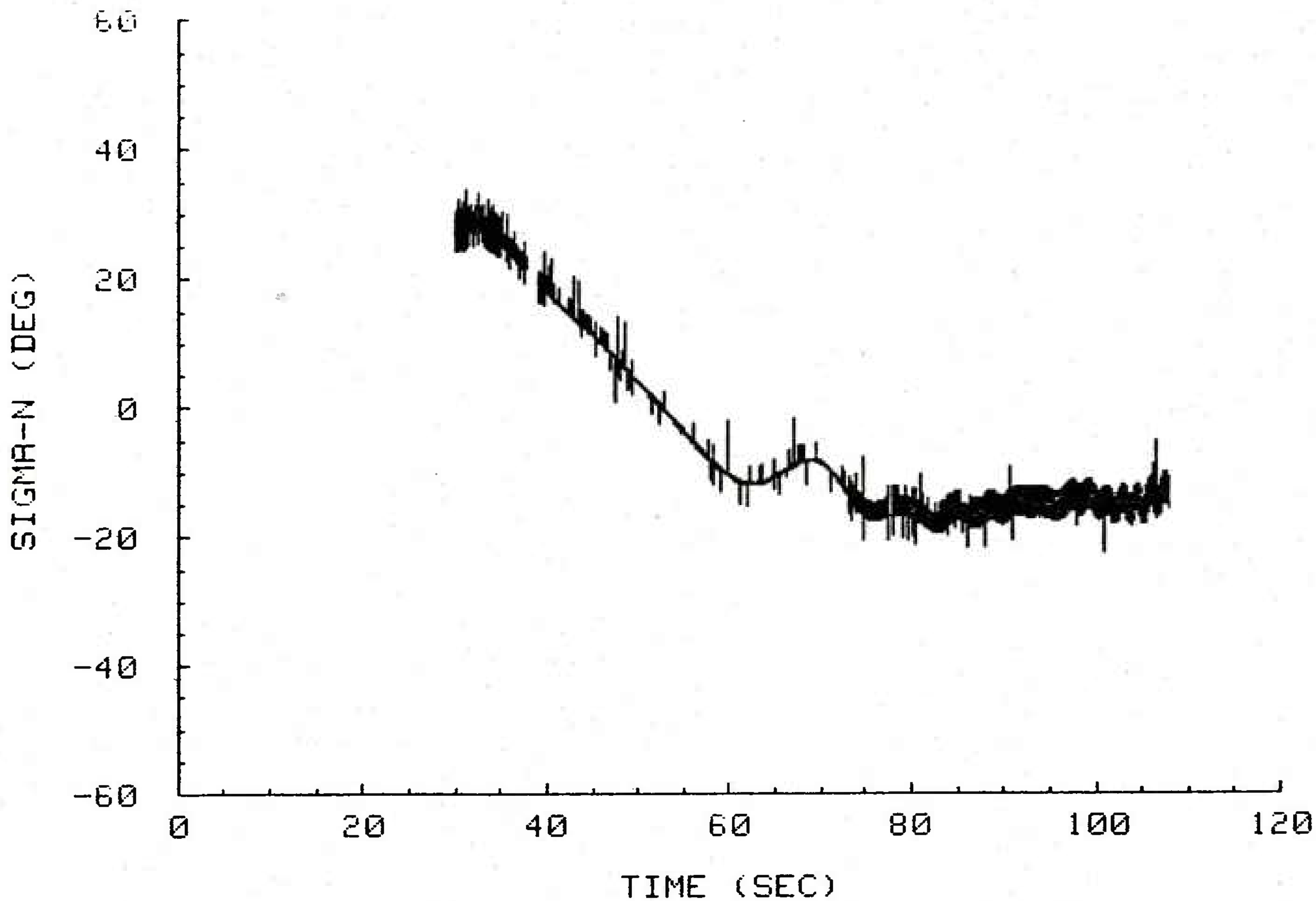


Figure 7a. Sigma N versus Time for Round C6.

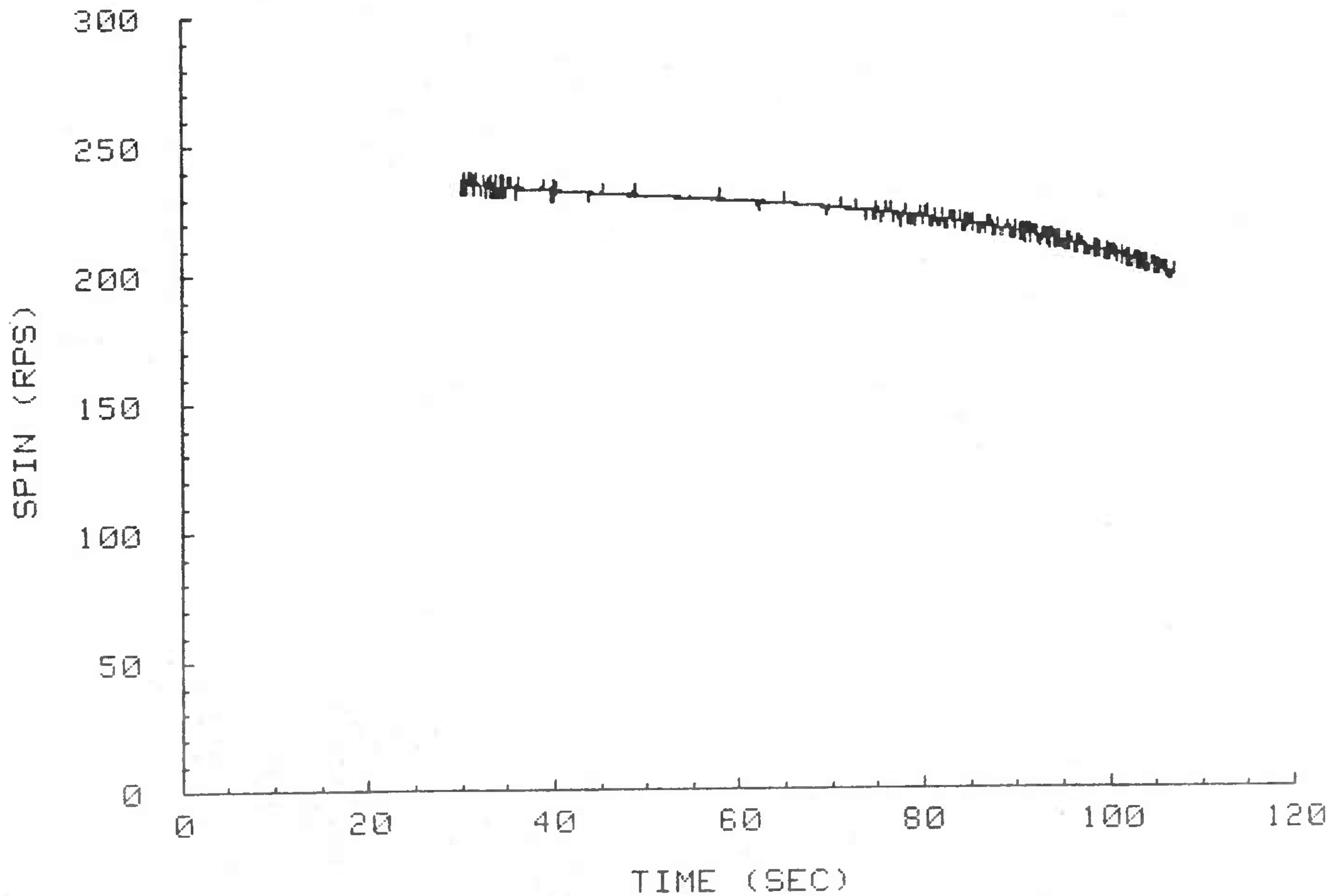


Figure 7b. Spin versus Time for Round C6.

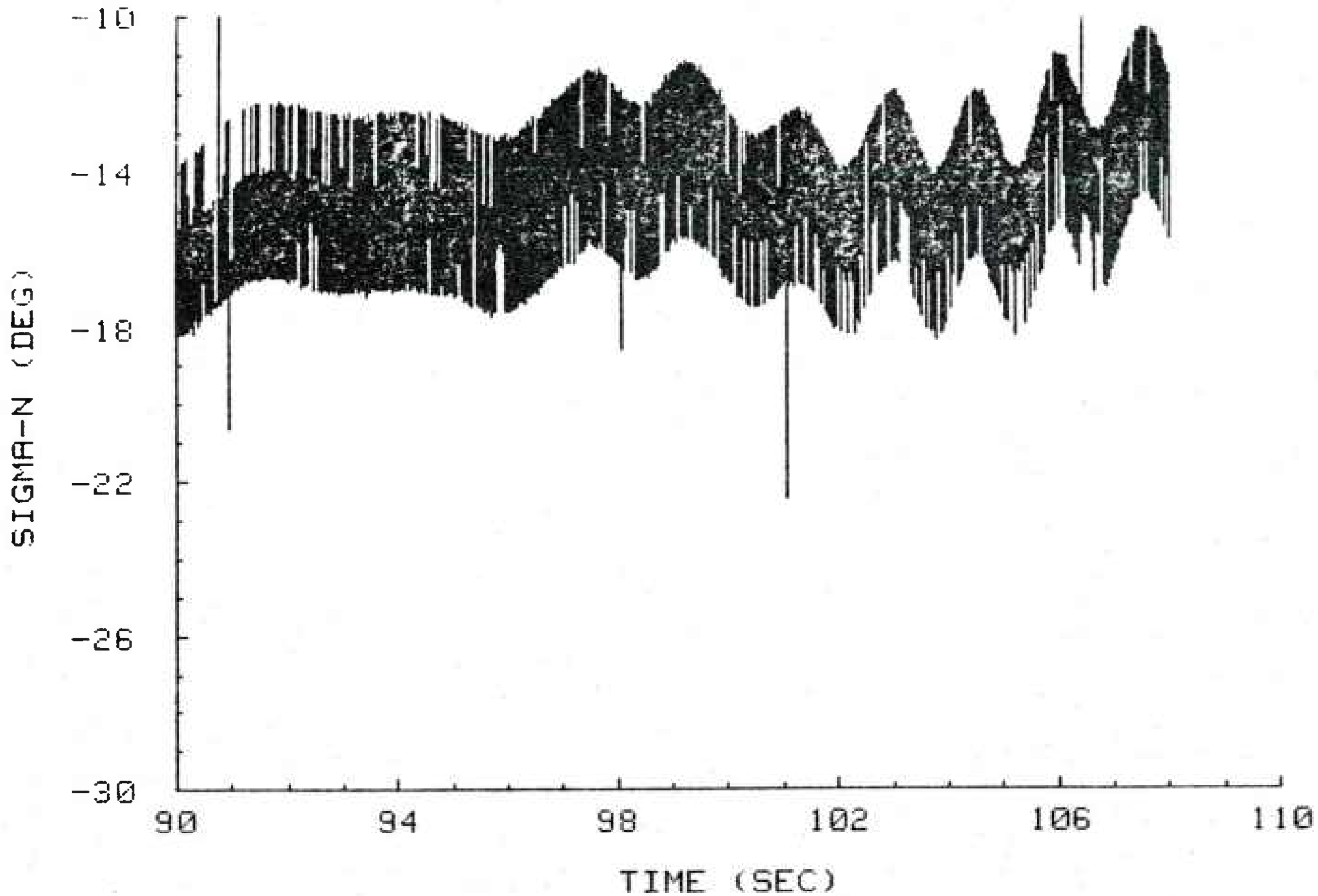


Figure 7c. Expanded Sigma N History (90-110 Sec) for Round C6.

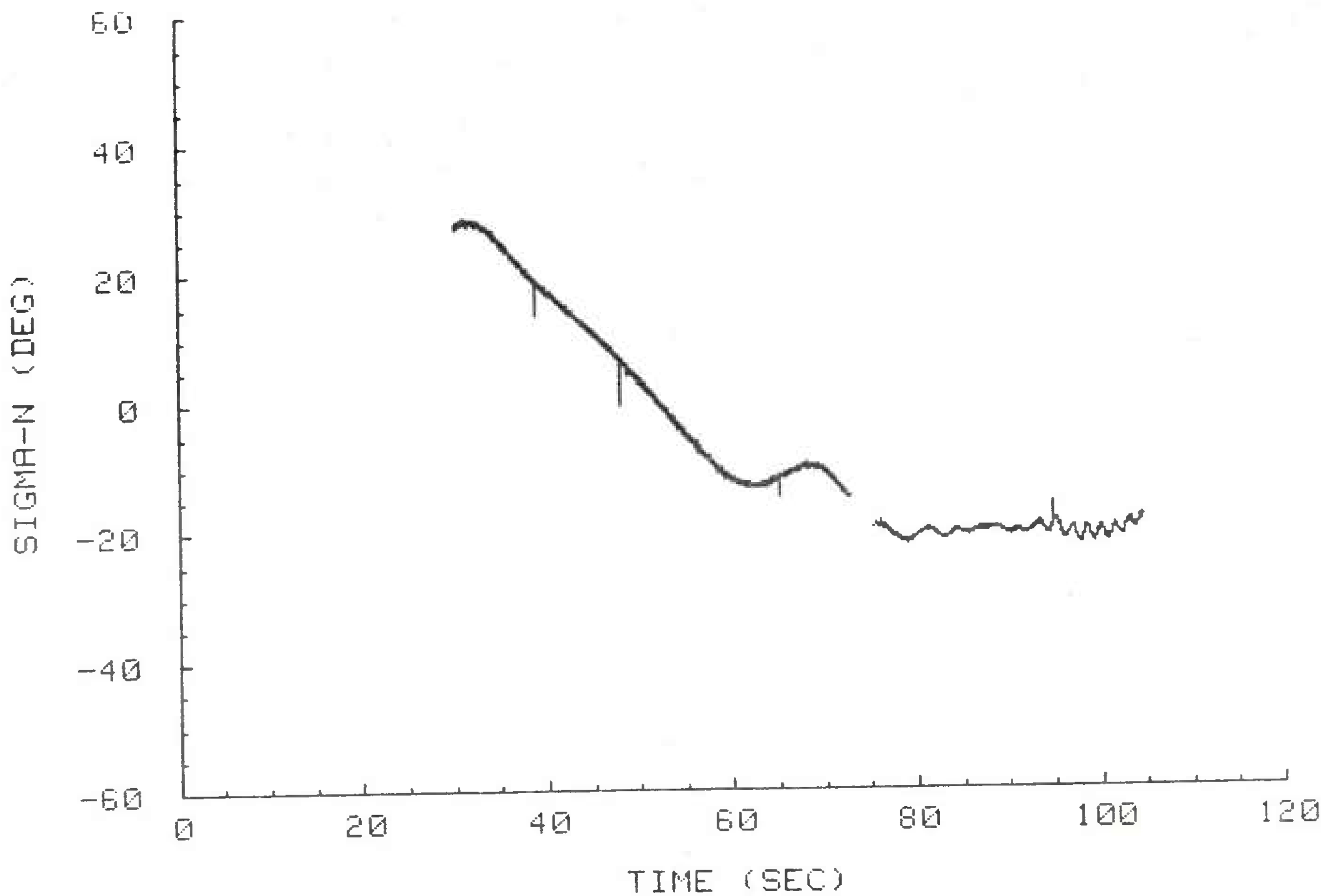


Figure 8a. Sigma N versus Time for Round D4.

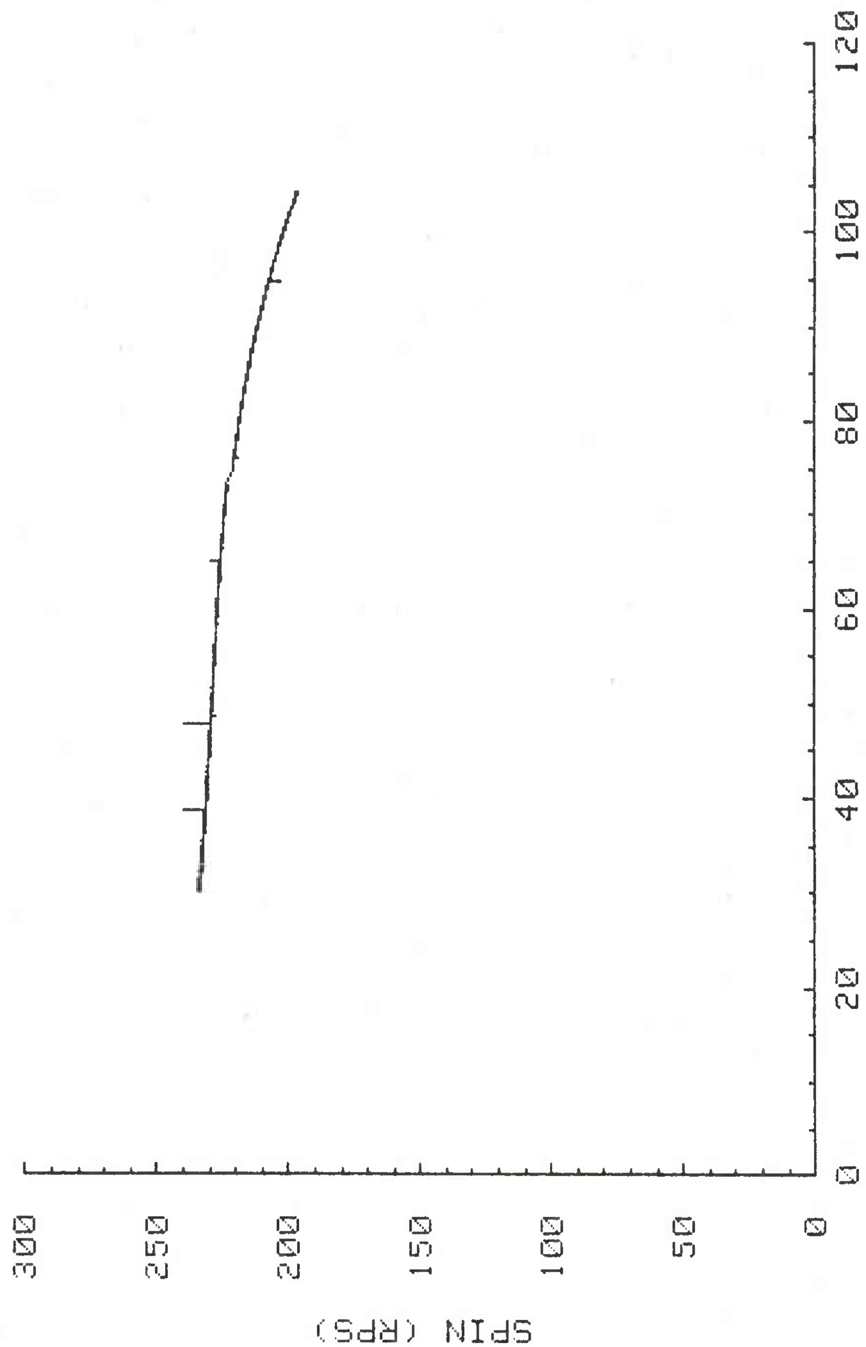


Figure 8b. Spin versus Time for Round D4.

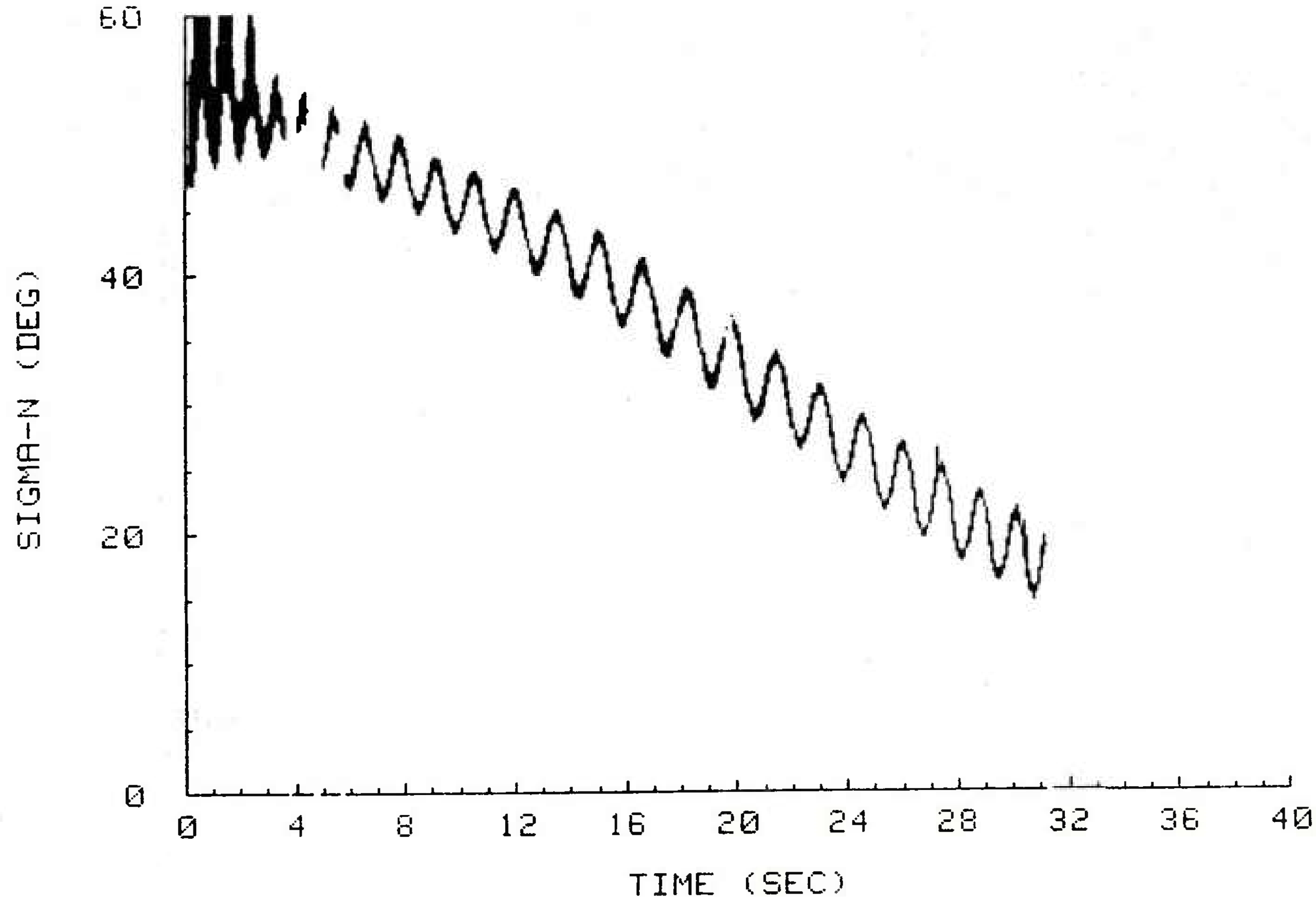


Figure 9a. Sigma N versus Time for Round A1.

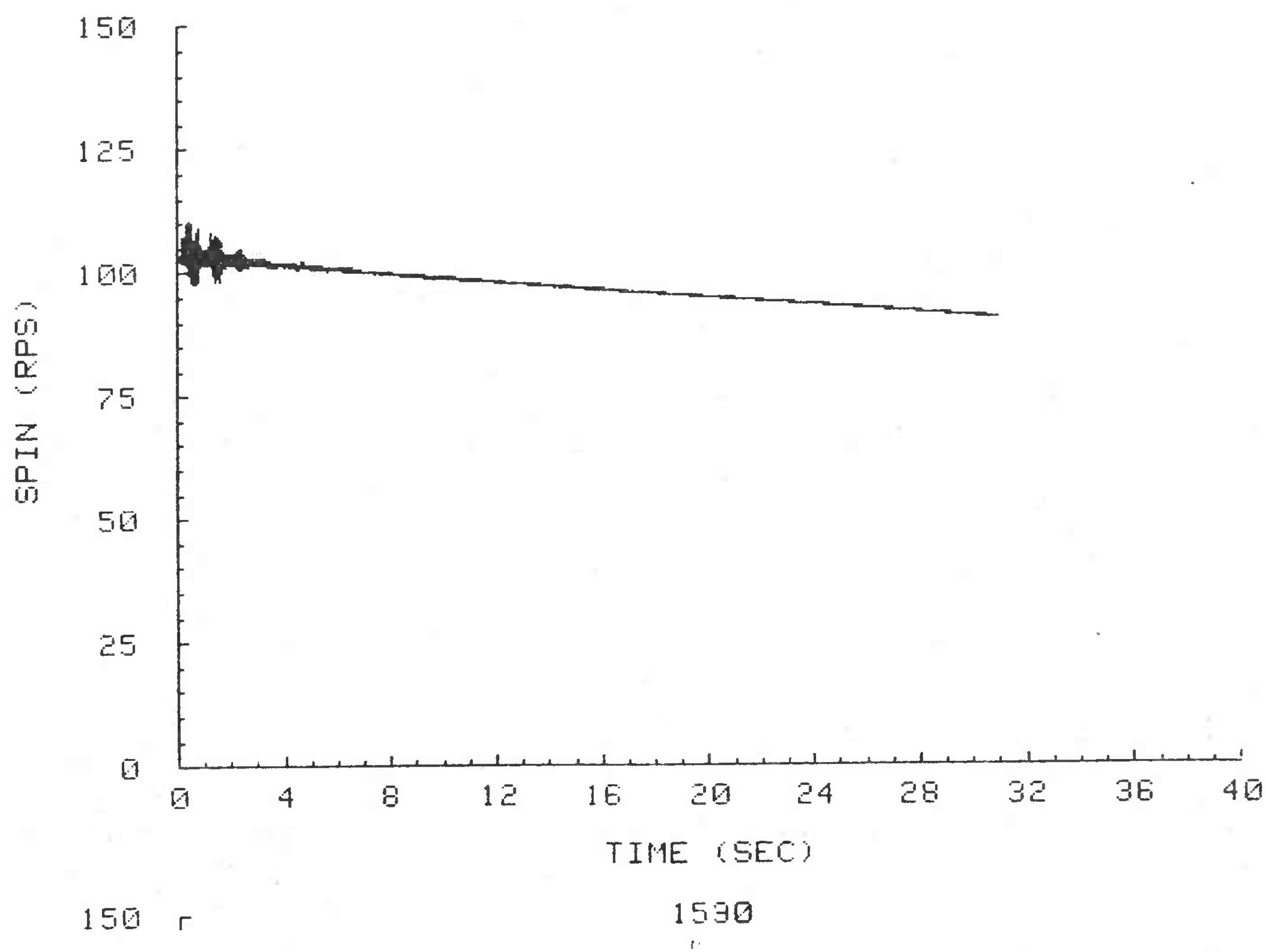


Figure 9b. Spin versus Time for Round A1.

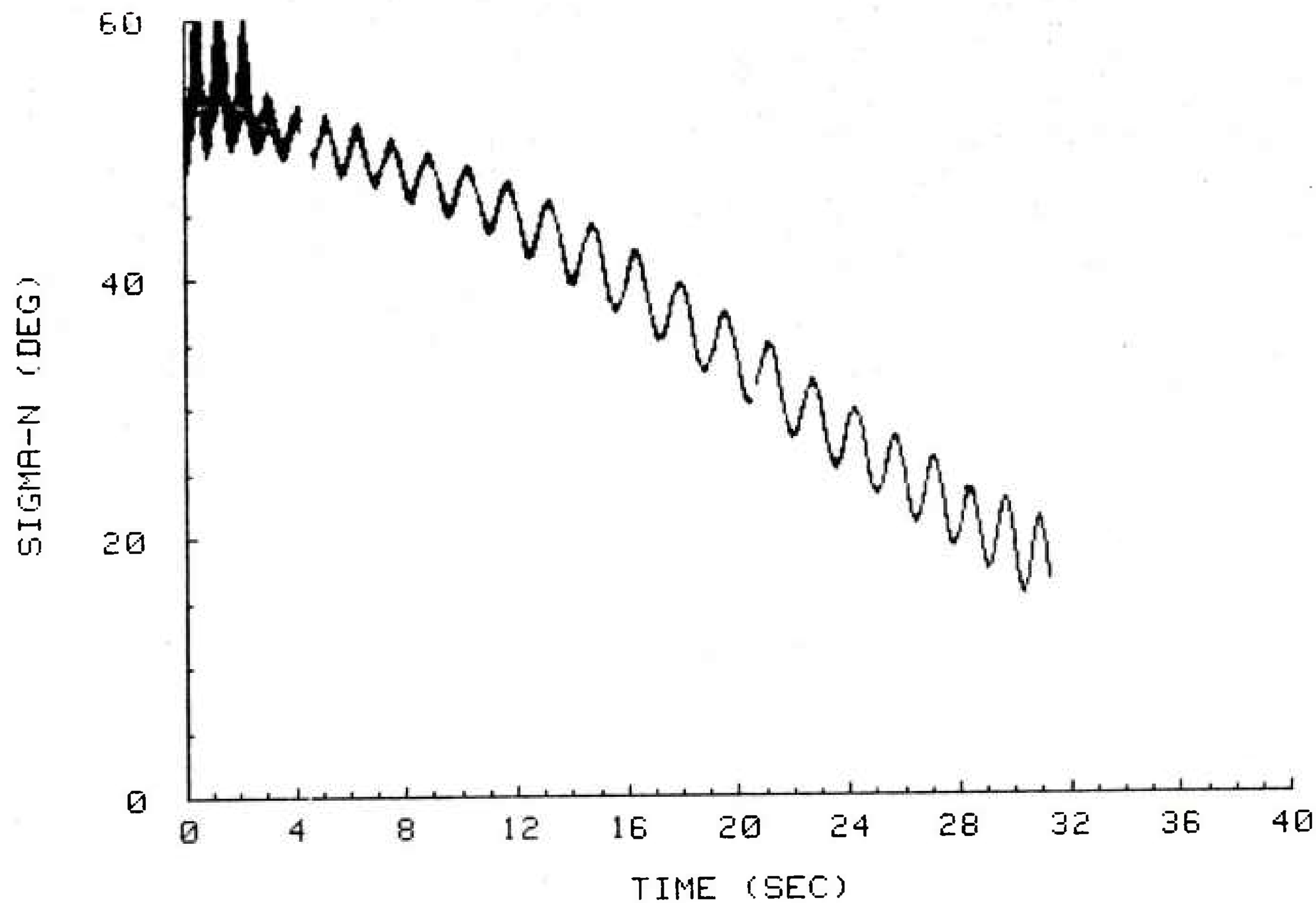


Figure 10a. Sigma N versus Time for Round A2.

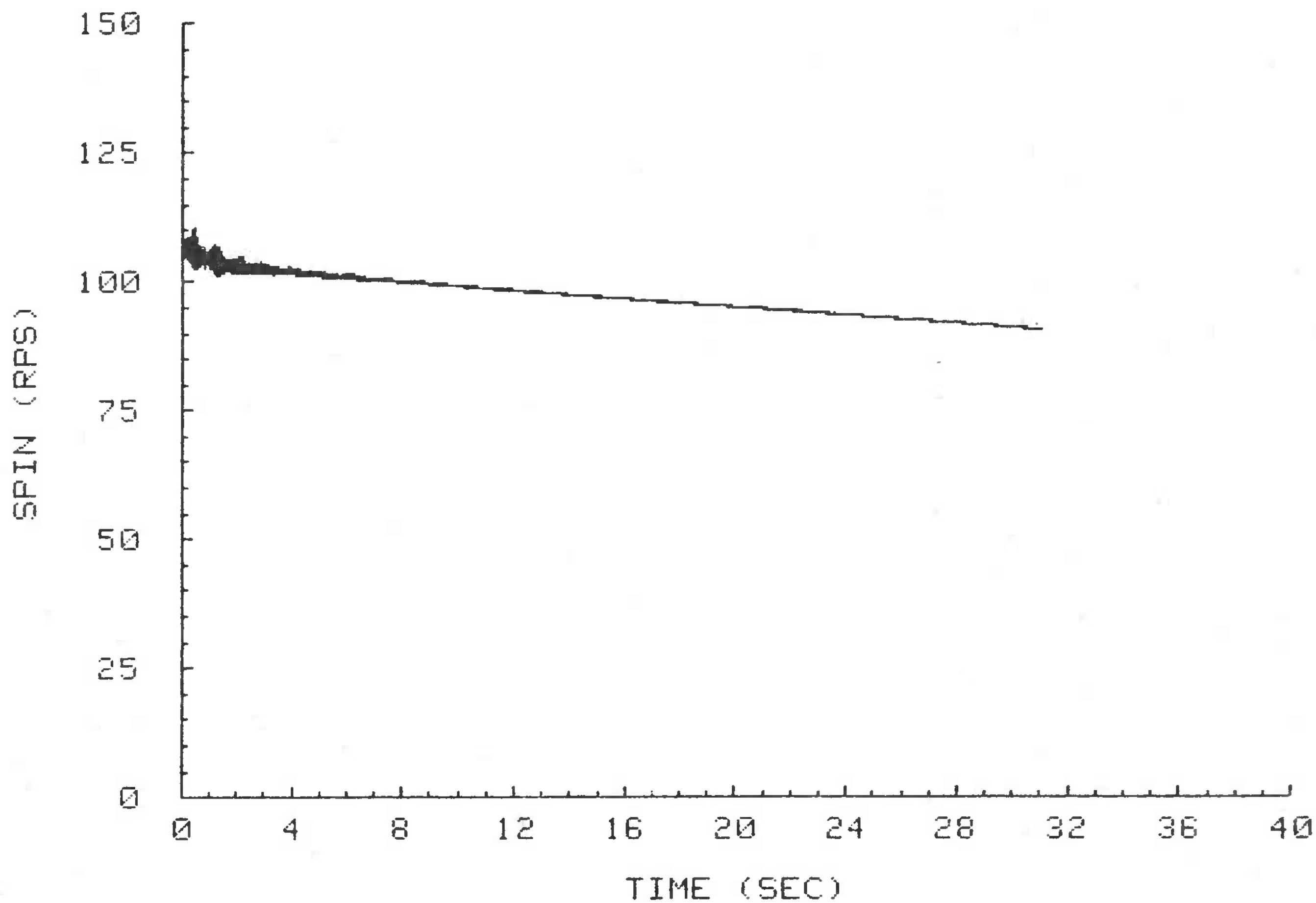


Figure 10b. Spin versus Time for Round A2.

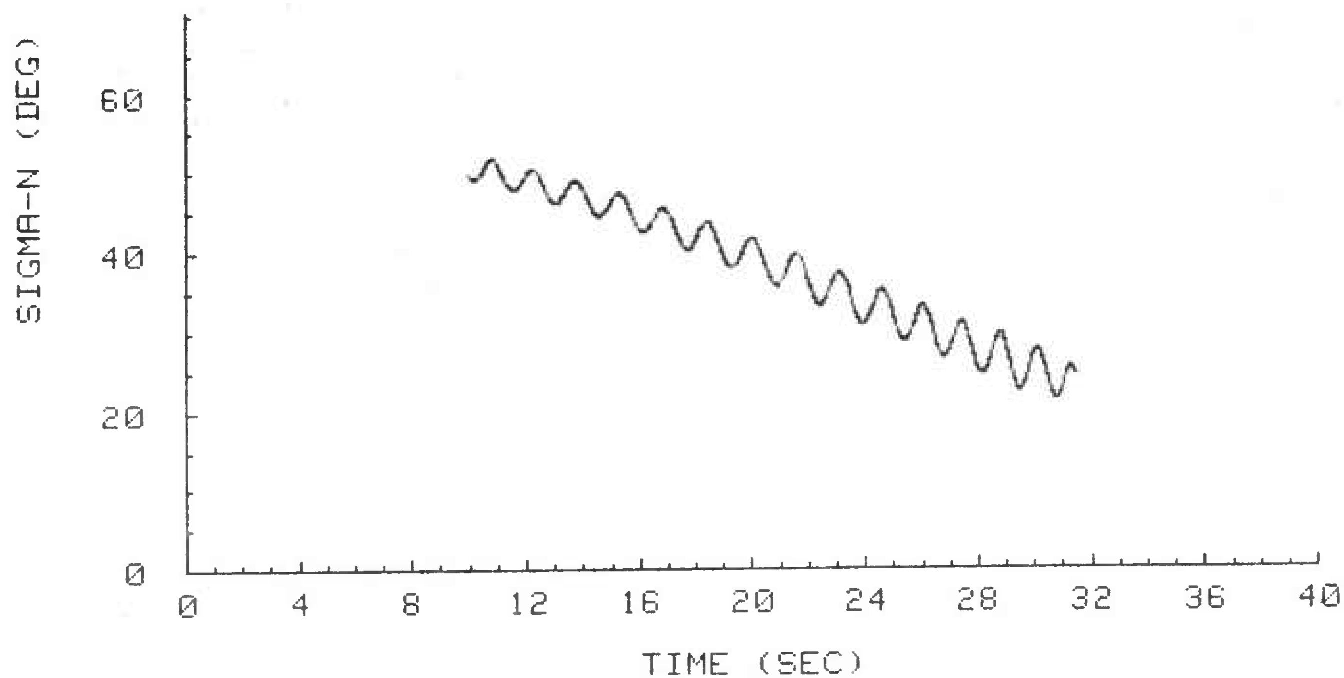


Figure 11a. Sigma N versus Time for Round C1.

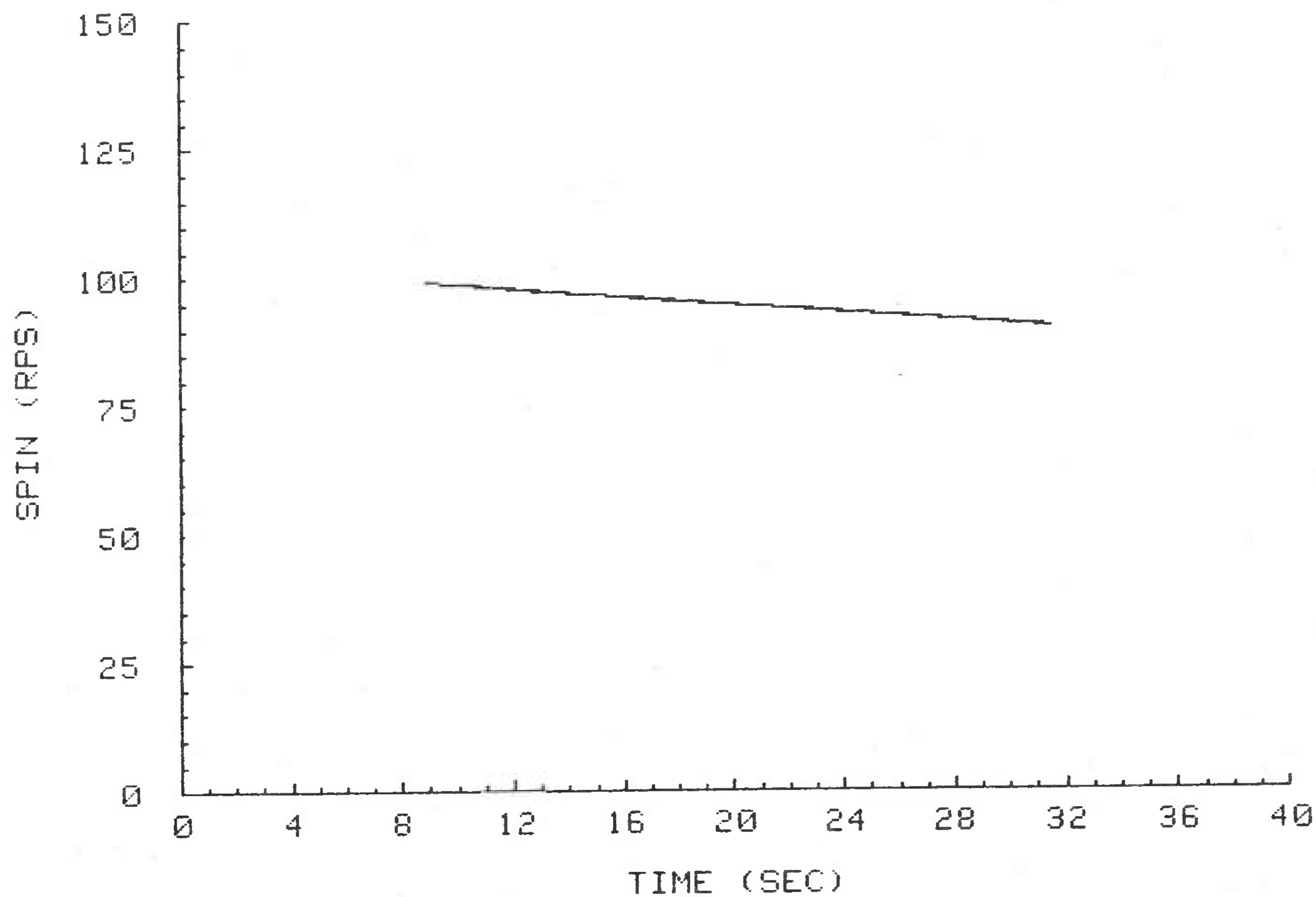


Figure 11b. Spin versus Time for Round C1.

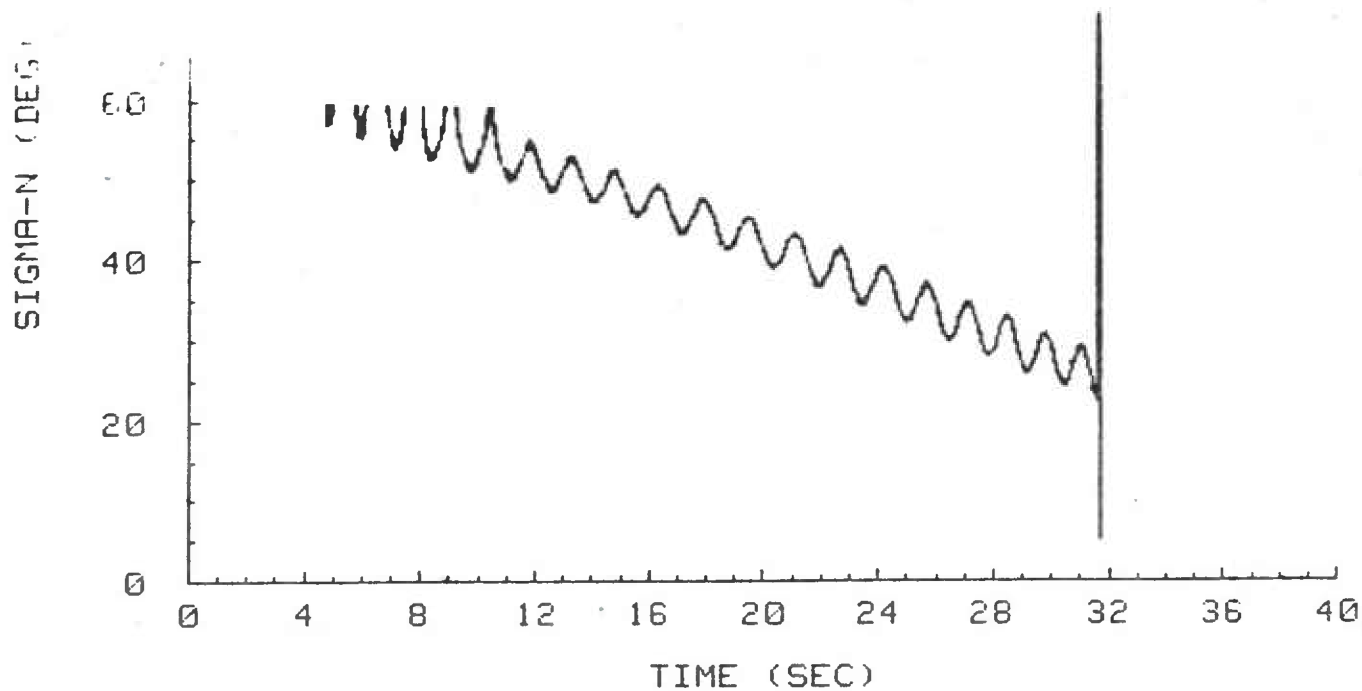


Figure 12a. Sigma N versus Time for Round D1.

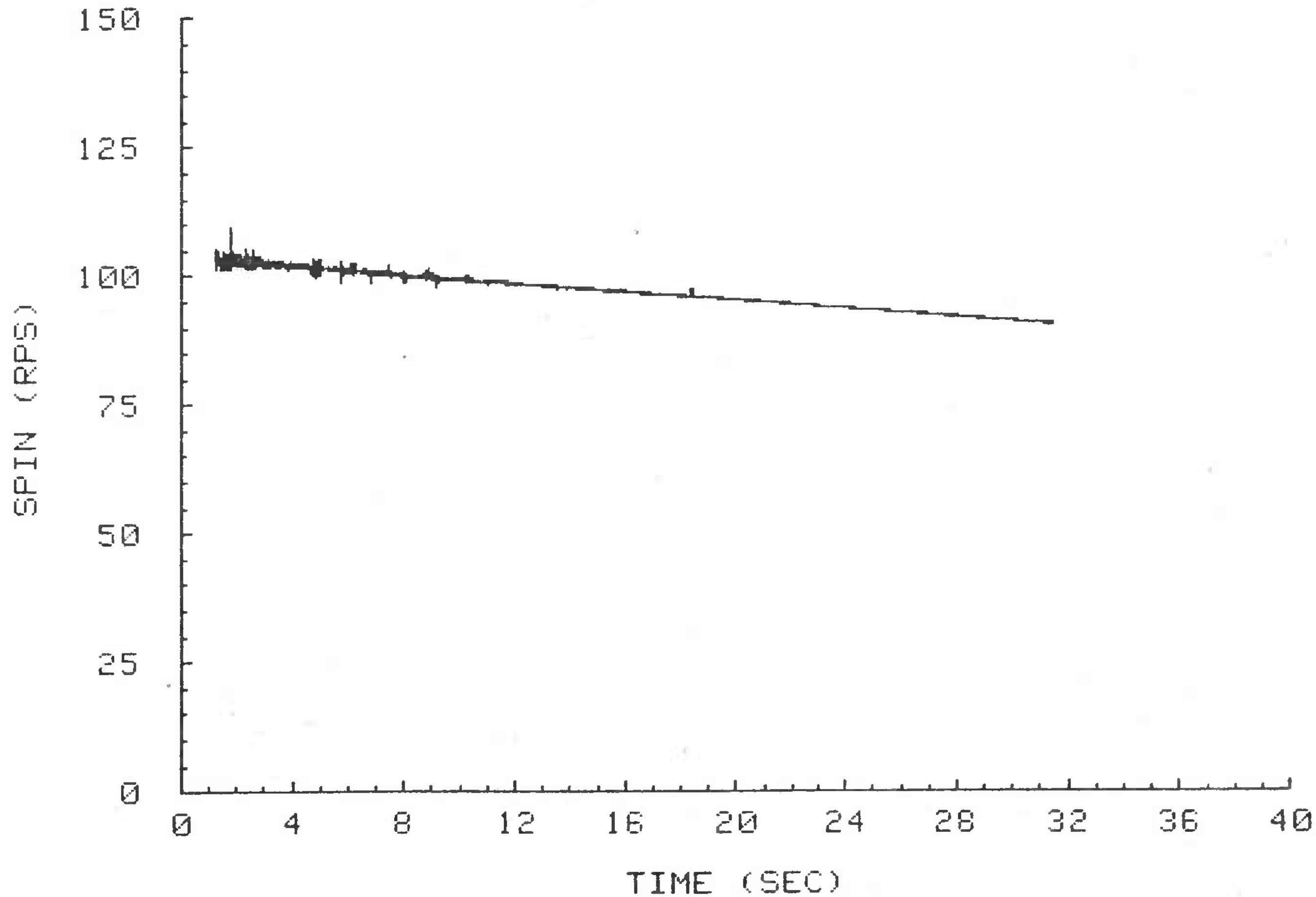


Figure 12b. Spin versus Time for Round D1.

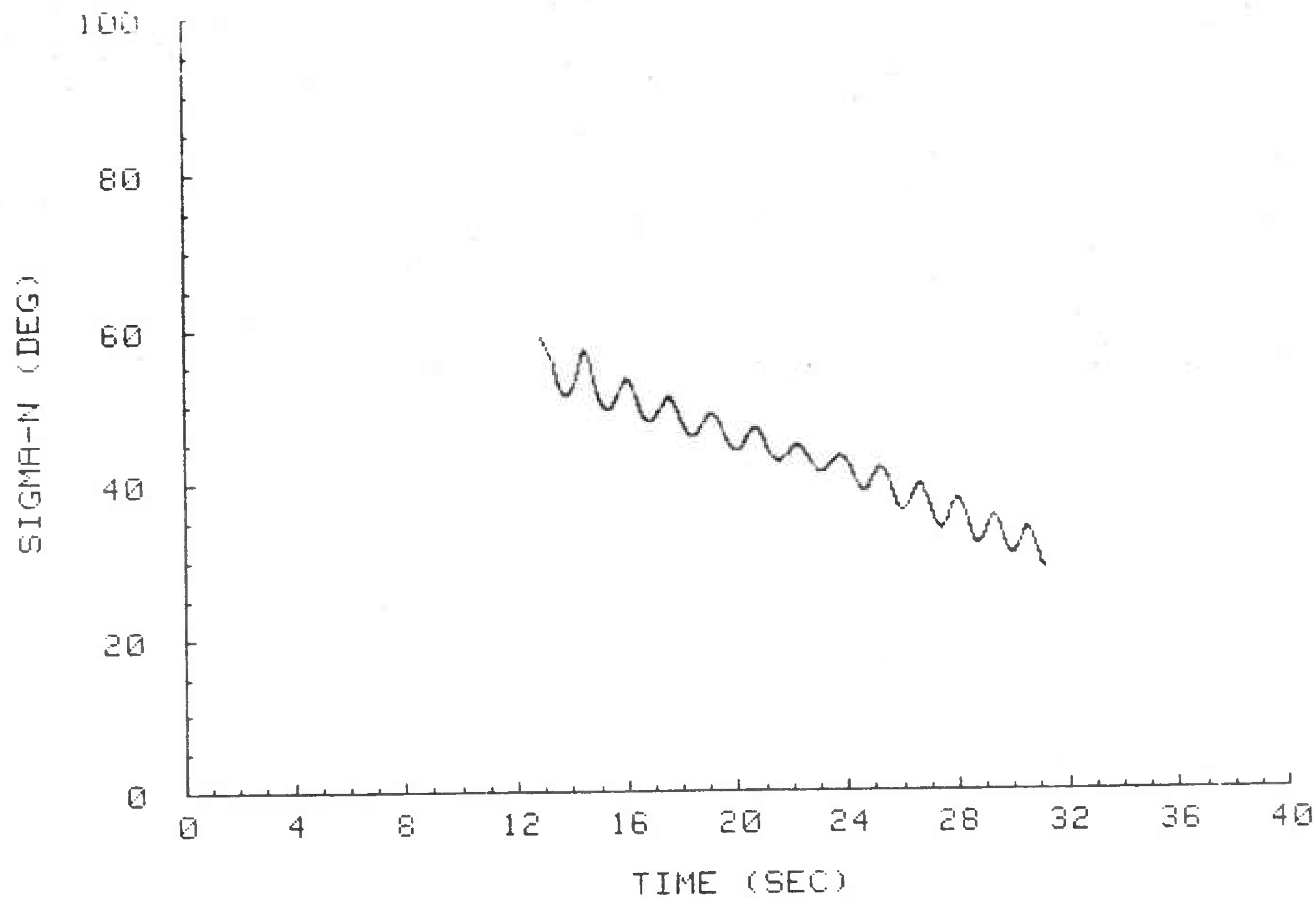


Figure 13a. Sigma N versus Time for Round D2.

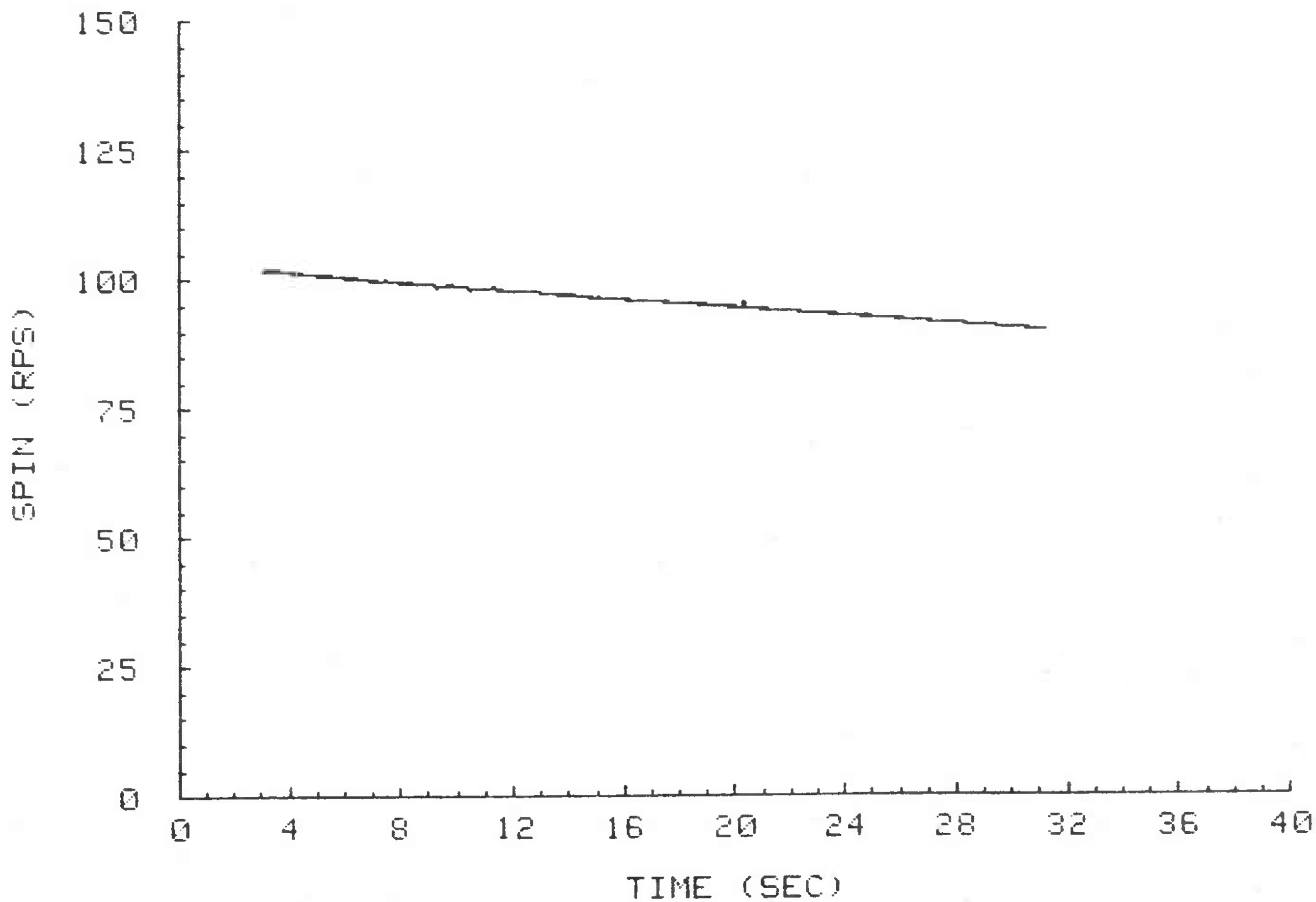


Figure 13b. Spin versus Time for Round D2.

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